Abstract

The present habilitation thesis, entitled **"Metal foams and metal foams-based composites"**, summarizes the academic, professional and research performances of the candidate Dr. Eng. Emanoil LINUL, after receiving the scientific title of Doctor of Engineering (2011), and until now . The author of the thesis, currently holds the teaching position of *Associate Professor*, full time, in the State of Functions of the Department of Mechanics and Strength of Materials of the Politehnica University Timisoara. At the same time, starting with 2018, the candidate is an *Associate Researcher* at the National Institute of Research and Development for Electrochemistry and Condensed Matter in Timisoara. This thesis presents an impressive collection of experimental and analytical approaches, in the field of Mechanical Engineering, regarding the mechanical behavior of advanced lightweight cellular materials.

The paper is structured in three main parts, divided in turn into five distinct chapters. The first part (§1) presents the achievements of the author, the second part (§2-4) contains the results of the research activity, and the last part (§5) includes the evolution of the career and the perspectives of personal development after obtaining the habilitation certificate. Also, the thesis contains 334 bibliographic titles, 118 figures, 21 tables, 61 equations and calculation relations, respectively 4 annexes.

THE FIRST PART of the habilitation thesis, **Chapter 1**, mentions the main scientific, academic and professional achievements of the candidate, obtained in the last 11 years from the public presentation of the doctoral thesis. After obtaining the scientific title of doctor, ***the research activity*** of the candidate was developed in four main topics, whose benchmarks are presented in Section 1.2.1. The first research topic is associated with metal foams, an area addressed since 2011 (§1.2.1.1). The following topic is associated with polymeric foams, a topic that extends the field of the doctoral thesis (§1.2.1.2). The third theme, initiated in 2016, is associated with ceramic foams (§1.2.1.3). The latest research topic reflects the field of 3D printed components, the stage developed in 2018 (§1.2.1.4). The most relevant scientific publications (§1.2.2), research (§1.2.3) and industry (§1.2.4) projects, and research internships (§1.2.5), associated with the candidate's research activity are, also presented. The results of the candidate's research activity were presented in national and international academic and scientific events through articles published in journals or in the volumes of conference proceedings. In the period 2011-2021, the candidate published over 120 scientific papers, of which 91 are indexed in the Web of Science or Scopus databases, in 61 of them the candidate being the first author or corresponding author. The entire portfolio of scientific achievements, on which this habilitation thesis is based, enjoys a good international visibility. Thus, so far, the author's papers have benefited from over 1750 citations identified in the Web of Science database (H-index = 29), respectively over 2080 citations identified in the Scopus database (H-index = 31). ***The academic achievements*** (§1.3) of the candidate

are materialized through the didactic activity carried out internally and internationally (§1.3.1), through the continuous professional training (§1.3.2), respectively through the functions and responsibilities assigned at the level of the Department, Faculty or University (§1.3.3). The preoccupation for the didactic activity materialized since the period of doctoral studies (2008-2011), the candidate performing classes of applications to various disciplines within the department. Regarding the university positions, since 2012 the candidate carries out teaching activities at the Polytechnic University of Timisoara, holding successively teaching positions such as: Assistant Professor (February 2012), Lecturer (February 2017) and Associate Professor (September 2019). Acquired professional prestige (§1.4.1), membership of prestigious professional organizations (§1.4.2), national and international professional collaborations (§1.4.3), the activity of reviewer of various specialized journals (§1.4. 4), respectively the awards and distinctions received (§1.5.5) constitute ***the professional achievements*** (§1.4) of the candidate. Moreover, the active involvement in the editorial board of some prestigious scientific journals, as well as the organization of various international scientific events, confirms and validates the professional prestige of the candidate.

THE SECOND PART of the habilitation thesis is structured on three chapters (Introduction, Metal foams and Metal foams-based composites), and includes the most important results regarding the author's personal scientific contribution. Comprehensively, the candidate's research activity is oriented towards modern engineering applications, with a constant emphasis on the design, optimization, manufacture and characterization of lightweight cellular materials and advanced composites based on cellular materials.

Chapter 2 is organized into four sections and presents a detailed introduction to the addressed research topic. In the first part of *Section 2.1* the cellular materials are defined, a general presentation of the natural cellular materials is made, respectively the cellular materials are classified according to the morphology of the cells and the way of their connection. Then, depending on the used matrix, the main types of synthetic cellular materials are listed, defined and presented. The properties of metal foams, the main metal alloys used for the manufacture of metal foams, as well as the microstructure of metal foams are the subject of the second half of *Section 2.1*. *Section 2.2* presents the methods for obtaining metal foams. Initially, a classification of metal foams is made based on „without assisted” and „with pressure” manufacturing methods. Subsequently, a detailed description of the processes for obtaining foams by casting and powder metallurgy is performed. Thus, the choice of the used constituents, the stages of the manufacturing processes, discussions and images with the foam microstructure are presented, and, finally, the advantages and disadvantages associated with each process are highlighted. *Section 2.3* presents the mechanical properties of metal foams, together with the main destructive and non-destructive methods for their determination. The influence of density, used alloy, test temperature and loading speed on the mechanical behavior of metal foams is described. Also, the regions of the stress-strain curve at compression are presented and, based on these characteristic regions, the main mechanical properties are defined. Moreover, in order to understand the mechanical behavior, studies from the specialized literature performed on different types of metal foams are presented. Functional and structural applications of metal foams are included in *Section 2.4*. The first part defines the criteria and factors that underlie the field of applicability of metal foams. Further, a distribution of metal foam applications in various industrial sectors is made. The last part presents the applications of metal foams, grouped according to the morphology of the cells and the type of application.

Chapter 3 presents the influence of temperature, anisotropy, loading direction, loading speed and density on the mechanical properties of metal foams. The studies focus especially on the collapse mechanisms that occur in the foam microstructure, the strength properties and the energy absorption performance. Moreover, according to the used test temperatures, various correlations are made between macrostructure, microstructure and the characteristic curves of the investigated foams. *Section 3.1* presents in detail the influence of test temperature (25, 150, 300 and 450°C) and of the loading direction (axial and radial) on the compressive mechanical properties of the cylindrical metal foam samples. At the end of the section, a comparison of the mechanical properties for the two loading directions is presented, depending on the test temperature. *Section 3.2* studies the mechanical behavior of metal foams, on cubic samples, under different loading conditions (three orthogonal directions), respectively different test temperatures (-196, 25 and 250°C). The emphasis is on the effect of the orientation and type of cells, as well as on the percentage of their distribution in the foam structure, on the mechanical properties. In addition, according to the test temperature and the loading direction, the relative percentage change of the normalized properties is presented. The main purpose of *Section 3.3* is to perform a statistical analysis of the microstructure of metal foams and to determine the mechanical characteristics under the double influence of density (0.35-0.55 g/cm^3) and loading speed (1.67·10^{-4} m/s - 3.72 m/s). Comparisons between quasi-static and dynamic results are presented. Also, the field of deformations on the surface of the specimens, resulting from the compression loads, is identified by drawing the surface deformation maps. *Section 3.4* addresses the influence of metal foam density (0.43-1.39 g/cm^3) on the Poisson's ratio. Initially, in order to determine the values of the Poisson's ratio, non-destructive experimental investigations are performed on disk samples, using the impulse excitation technique. Subsequently, the dependence of the Poisson's ratio on the porosity of the metal foam was modeled analytically using the linear approximation method and based on the power-law relationship of percolation.

Chapter 4 focuses on the influence of test temperature (range 25-450°C) on the mechanical properties of metal foam-based composites. The main results (characteristic curves, variation of properties, deformation process of samples, macro- and micro-structural analysis) of empty tubes and foam-filled tubes under axial and radial compression loading are presented. Then, depending on the temperature, the results of the two sample configurations (empty tube and foam-filled tube), respectively of the two types of loads (axial and radial) are compared. Moreover, according to the test temperature and the configuration of the specimens, some correlations between macrostructure, microstructure and the characteristic curves at quasi-static compression are proposed. Finally, in-depth discussions are presented on the effect of plastic hinges and the brittle-to-ductile transition, both on the strength properties and energy absorption capacity, as well as on the collapse mechanisms that take place and the foam-tube interaction.

THE THIRD PART of the habilitation thesis, **Chapter 5**, briefly presents the plan for the evolution and development of the career from a scientific, academic and professional point of view. In order to improve personal and institutional prestige, the general objective of career development is outlined on two main approaches. The first approach is based on the acquired results and the current experience of the candidate; more precisely, the directions developed so far, in the field of training and development of the activity, which have been partially investigated and which require a detailed deepening. The second approach is represented by obtaining new results and important knowledge, by identifying current directions and development opportunities. Regarding ***the development of the scientific career***, future research will be carried out in three main directions: natural and synthetic cellular materials (§5.2.1), 3D printed components (§5.2.2) and composite structures based on cellular materials (§5.2 .3). In order to support the mentioned research directions and for the continuous development of the scientific career, in Section 5.2.4, solutions that lead to their realization are presented. ***Academic career development*** (§5.3) is identified on the basis of three main levels, namely: individual, collegiate and student activities. For each mentioned level, the candidate presents concrete objectives. ***The professional career development*** (§5.4) aims at recognizing the international professional performances of the candidate. In this sense, the author proposes to achieve several specific objectives.

The habilitation thesis ends with ***the list of bibliographic references*** associated with the three parts and ***the section of Annexes*** that contains the list of figures (Annex 1), the list of tables (Annex 2), the list of notations, abbreviations, acronyms (Annex 3) and the list of 10 relevant scientific publications (Annex 4).